PANAMA RAINFALL.

By H. G. CORNTHWAITE, Chief Hydrographer.

[Dated: Balboa Heights, C. Z., Jan. 31, 1919.]

SYNOPSIS.—The writer sketches the geographical distribution of the rainfall in Panama, and follows with an account, with tables and figures, of monthly and hourly precipitation, local showers, and excessive rainfall. Whatever rain occurs on the Isthmus must be attributed to local convection currents in conjunction with the deflective effects of hills and mountains on such winds as there are.

The rainfall on the north side exceeds that on the south side of the Isthmus, and is greatest on the north coast and locally on the higher portions of the Caribbean slope. The mean annual rainfall at Colon is 129.04 inches; at Porto Bello 169.15 inches, and at Balboa, 91.61 inches.

An excessive downpour in a brief period, probably 2.48 inches in 5 minutes at Porto Bello, May 1, 1910, seems to have been the most intense rainfall ever recorded.—H. L.

"(3) Cyclonic circulation."

Since the Isthmus of Panama is in that section of the globe where the influence of convection is very great and where cyclonic disturbances are almost unknown, it follows that the greater part of the Isthmian rainfall must be attributed to the first two processes mentioned above.

Panama is situated in the Torrid Zone, where tropical weather conditions prevail. The year is divided into two seasons, a dry season of approximately four months duration, January to April, inclusive, and a rainy

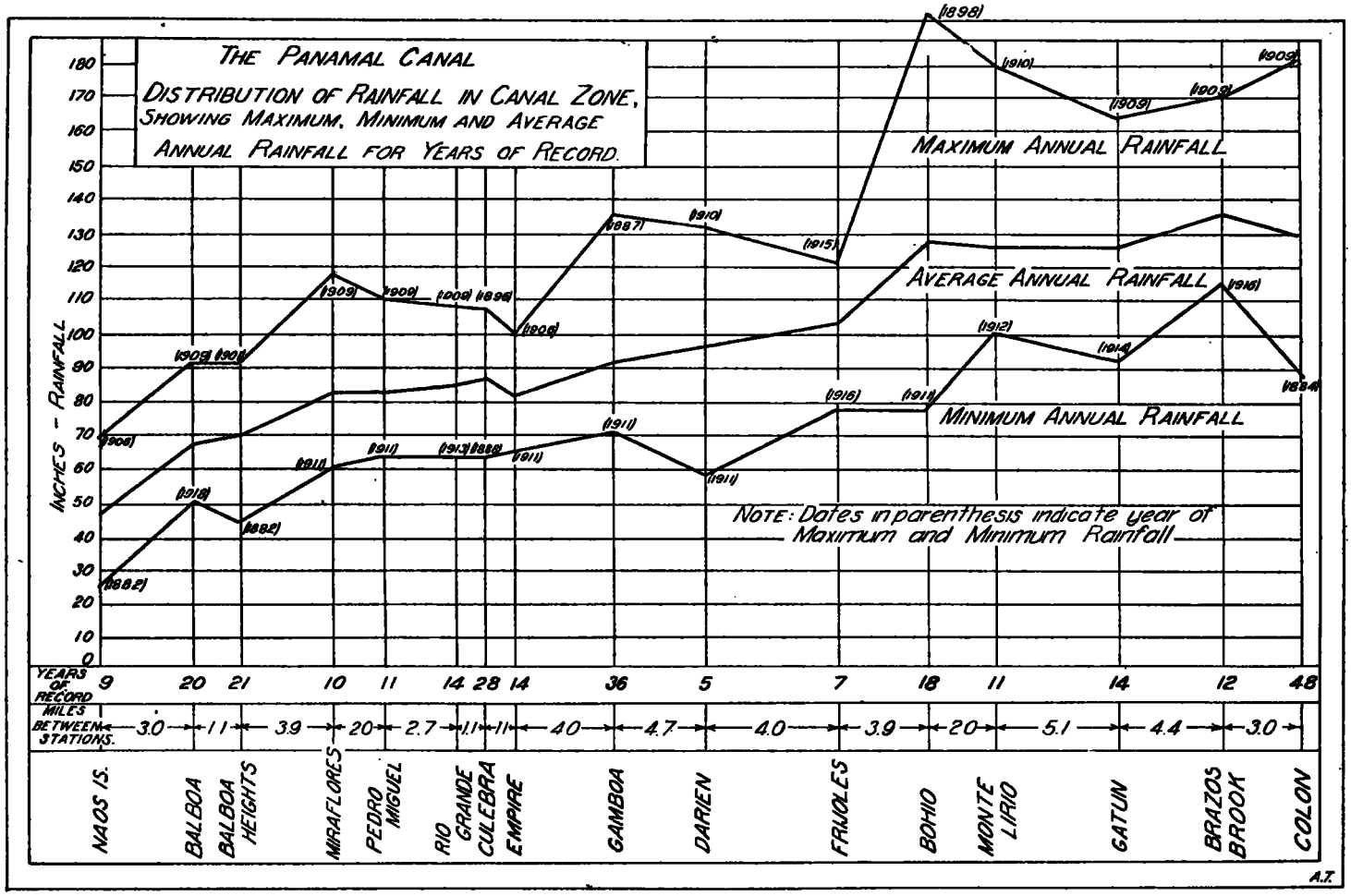

FIG. 1.

[1] "The cause of rainfall is to be found in the operation of certain general principles of physics, influenced more or less by local conditions. Rainfall is due to the condensation and precipitation of water vapor in the atmosphere, which has been derived primarily from the ocean by the process of evaporation. Whenever from any cause the moisture-laden air is sufficiently cooled, condensation and consequent precipitation take place. Three processes are primarily concerned in the production of rain, acting either singly or in combination. These factors are:

"(1) Convective currents [local].

"(2) Hills and mountains, which cause deflection of atmospheric currents.

[1] Quoting in part from article by C. M. Saville on the hydrology of the Panama Canal.

season extending over the remaining eight months of the year.

GEOGRAPHICAL DISTRIBUTION OF RAINFALL.

Rainfall in the Canal Zone and vicinity is heaviest along the Atlantic coast and in sections of the upper Chagres River drainage basin, diminishing gradually as the Pacific coast is approached. Practically all of the moisture-laden winds blow from off the Atlantic and the greater percentage of the surplus moisture carried by these winds is precipitated on the Atlantic side of the continental divide.

A large percentage of the rainfall in the Canal Zone is of the afternoon thundershower type, caused by con-

vective air circulation resulting from the excessive heating of the land surface during the daytime. This rain producing agency is less active out in Panama Bay, which accounts for the abrupt decrease in rainfall on Naos Island and Taboga, compared with the rainfall on the mainland.

The lightest annual rainfall of record on the Isthmus was 25.14 inches on Naos Island in 1882. The total rainfall at Taboga during the year 1918 was but 30.09 inches, and a long period record at Taboga probably would show still lighter rainfall.

The heaviest average annual rainfall of any station on the Isthmus is approximately 170 inches at Porto Bello, favorably located on the Atlantic coast near the headwaters of the Boqueron arm of the Chagres River. The total rainfall at Porto Bello in the year 1909 amounted to 237.28 inches. This is the heaviest annual rainfall of record at any station on the Isthmus, and it is exceeded in only a few known regions of the earth.

Figure 1 shows the distribution of annual rainfall across the Isthmus, as well as the maximum range in yearly rainfall at the various stations.

The annual rainfall in Panama is much less variable and more *dependable* than the rainfall in many sections of the Temperate Zone. This characteristic of Isthmian rainfall is valuable in connection with the operation of the Panama Canal, as it insures a dependable water supply. Figure 2 shows the variability of annual rainfall in the Canal Zone compared with the rainfall at selected stations in the United States. The curves show maximum and minimum annual rainfall in percentages of the annual means.

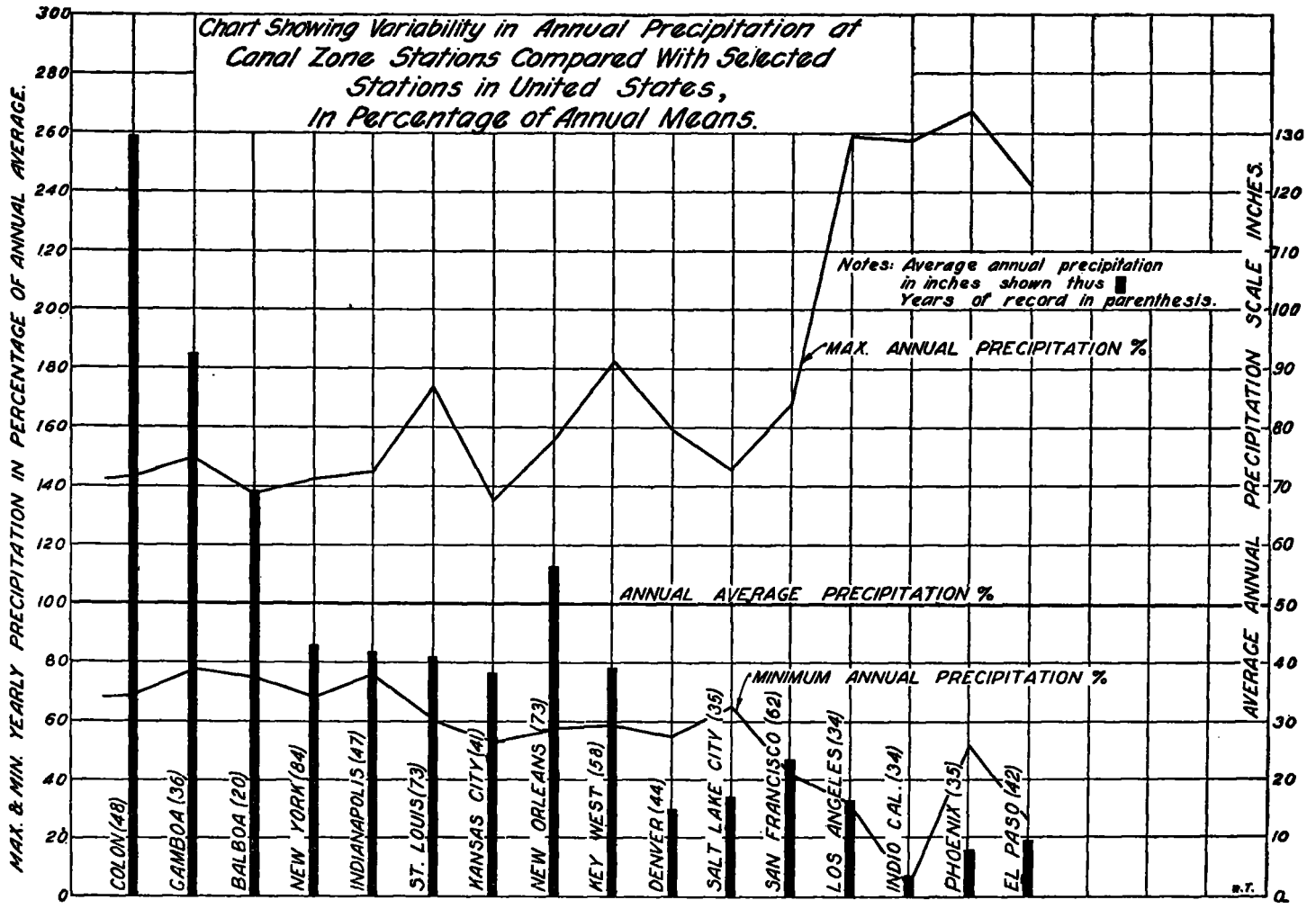

FIG. 2.

MONTHLY DISTRIBUTION.

The monthly distribution of rainfall at selected stations in the Canal Zone and vicinity is shown on figure 3. The season of the year from January to April, inclusive, is general recognized as the dry season on the Isthmus. Rainfall in the dry season usually consists of light local showers, but heavy rains of a more general character occur at times along the Atlantic coast accompanying storms of the "norther" type that occassionally reach as far south as the Atlantic coast of the Isthmus during the dry season.

The rainy season extends over the remaining eight months of the year. The lines of demarkation between dry-season and rainy-season conditions are not constant nor always clearly marked. In some years the dry season begins as early as December 1, while in other years rainy season conditions continue until the end of January or later.

March is usually the month of least rainfall and May and November are the months of heaviest rainfall.

An inspection of figure 3 shows that the rainfall at Bocas del Toro is somewhat lighter than the Colon rain-

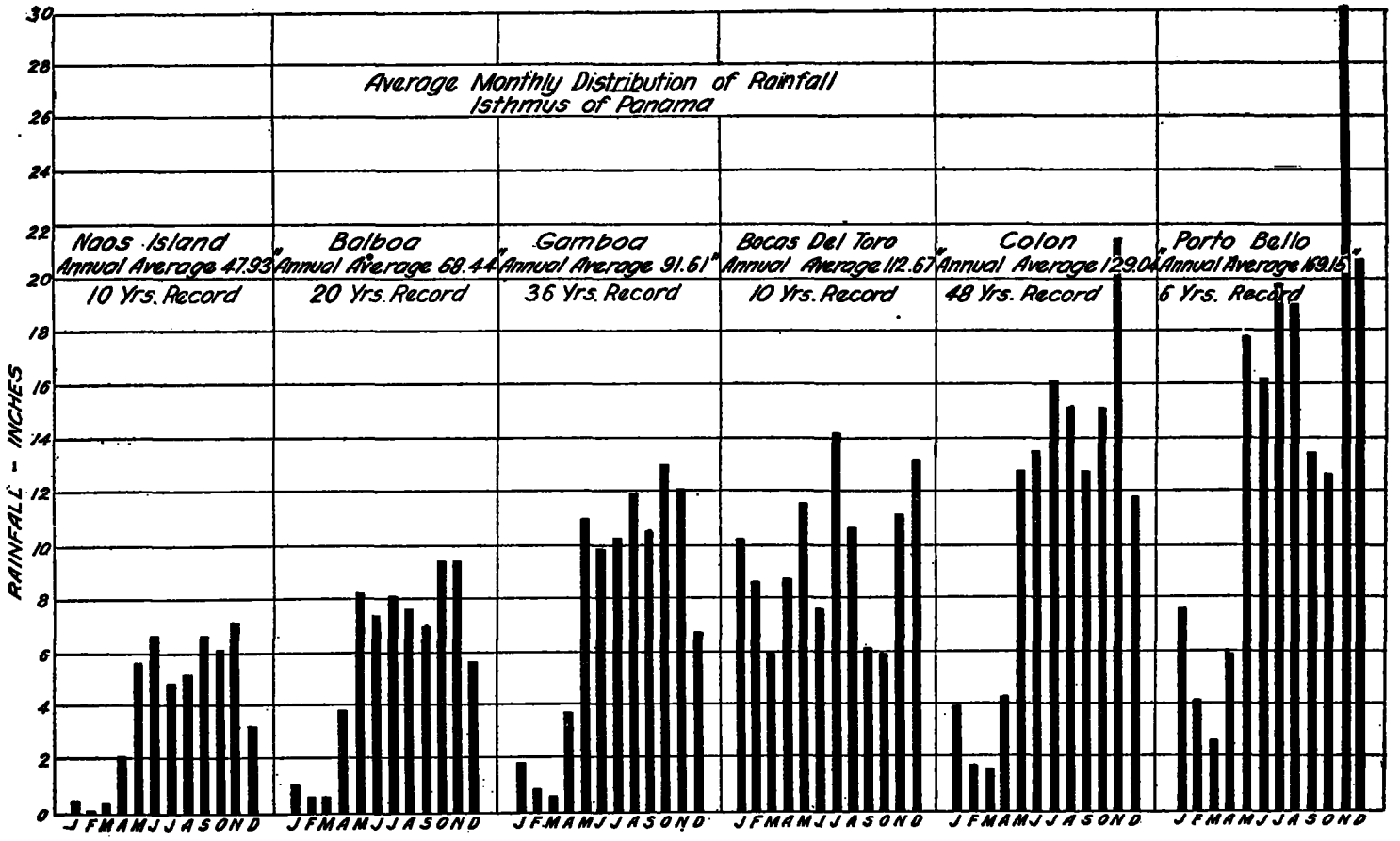
Average Monthly Distribution of Rainfall
Isthmus of Panama
RAINFALL - INCHES
Naos Island
Annual Average 47.93"
10 Yrs. Record
Balboa
Annual Average 68.44"
20 Yrs. Record
Gamboa
Annual Average 91.61"
36 Yrs. Record
Bocas Del Toro
Annual Average 112.67"
10 Yrs. Record
Colon
Annual Average 129.04"
48 Yrs. Record
Porto Bello
Annual Average 169.15"
6 Yrs. Record
J F M A M J J A S O N D

FIG. 3.

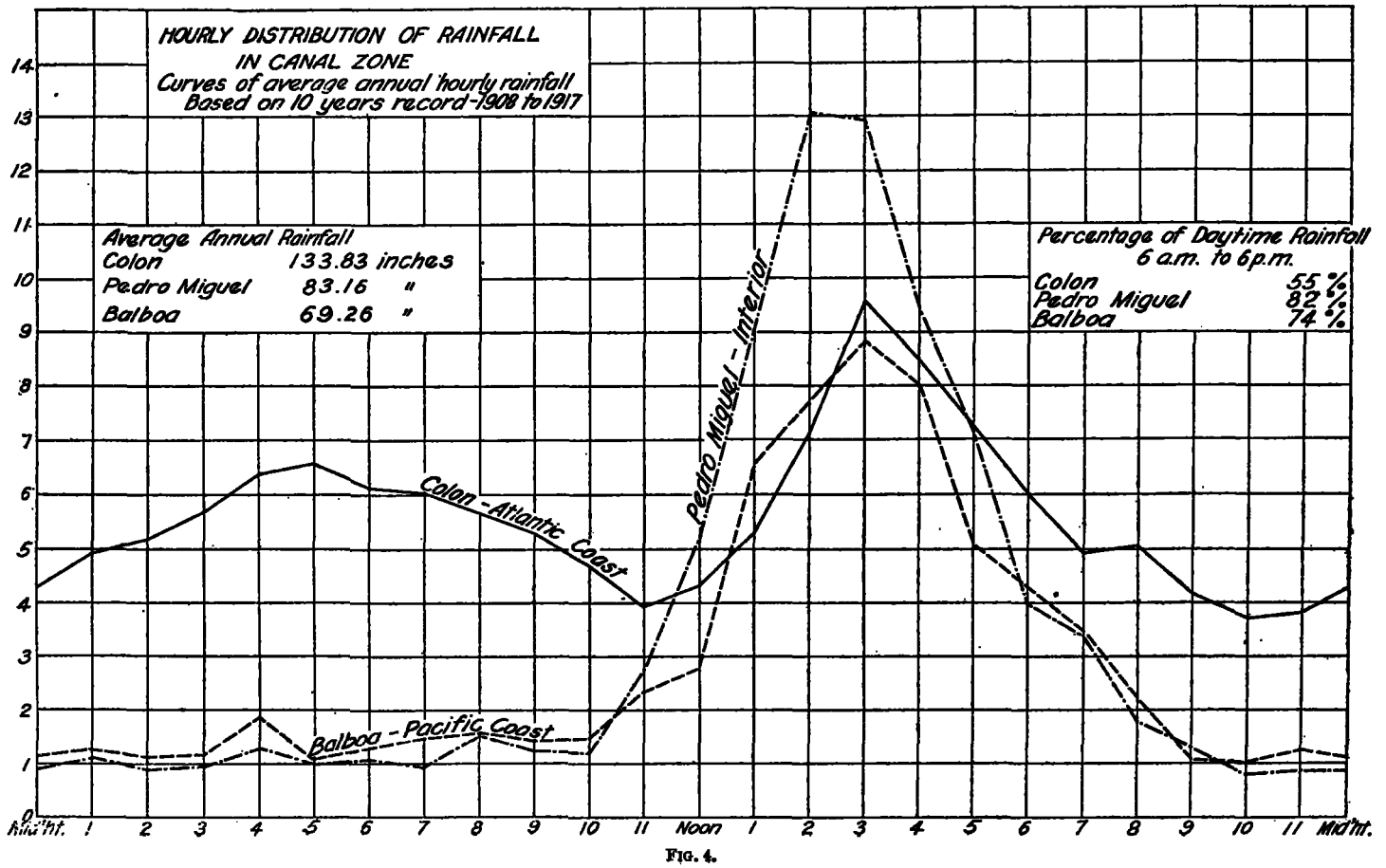
HOURLY DISTRIBUTION OF RAINFALL
IN CANAL ZONE
Curves of average annual hourly rainfall
Based on 10 years record-1908 to 1917
Average Annual Rainfall
Colon 133.83 inches
Pedro Miguel 83.16 "
Balboa 69.26 "
Percentage of Daytime Rainfall
6 a.m. to 6 p.m.
Colon 55 %
Pedro Miguel 82 %
Balboa 74 %
Colon - Atlantic Coast
Pedro Miguel - Interior
Balboa - Pacific Coast
Midnt. 1 2 3 4 5 6 7 8 9 10 11 Noon 1 2 3 4 5 6 7 8 9 10 11 Midnt.

FIG. 4.

fall, but it is remarkable principally on account of its radically different monthly and seasonal distribution. There are two periods of heavy rainfall at Bocas, one about July and another in December and January. There are also two periods of light rainfall, one in March and another in September–October. There is no clearly marked dry season at Bocas, as considerable rain falls during the driest months. The reason for this radically different rainfall distribution at Bocas del Toro is not clear, but it probably is due to the character and direction of prevailing winds and the position of adjacent mountain ranges.

HOURLY DISTRIBUTION.

A large percentage of Panama rainfall comes in the form of afternoon tropical thundershowers. The period from 2 p. m. to 3 p. m. is the hour of heaviest rainfall as a general rule. The curves of average hourly rainfall show (fig. 4) a principal period of minimum precipitation around 10 p. m., and a secondary minimum in the early morning.

Nearly half of the total rainfall occurs at night along the Atlantic coast, while near the Continental Divide and along the Pacific coast only about 25 per cent or less of the total rainfall occurs at night.

The heavier night rainfall along the Atlantic coast seems to be due to a smaller percentage of afternoon thundershowers and a larger percentage of rains of a more general character along the Atlantic coast than occur over the other sections of the Isthmus. Many of these general rains occur at night.

The chilling of the land surface during the night by the escape of heat through outward radiation and the upward deflection of the winds in passing over the land mass also tend to increase the night and early morning precipitation along the Atlantic coast, by cooling the warm, humid winds from the Atlantic, until the dew point is passed and condensation and precipitation occur.

The following table shows the percentage of daytime rainfall (6 a. m. to 6 p. m.) at three selected stations, based on 10 years' records:

Stations.	Daytime precipitation.	Annual total.
	Per cent.	*Inches.*
Balboa (Pacific coast)	74	69.25
Pedro Miguel (near Continental Divide)	82	83.16
Colon (Atlantic coast)	55	133.83

Curves of average hourly rainfall are shown on figure 3.

LOCAL SHOWERS.

Many heavy Isthmian showers are of extremely local character and very limited extent. An examination of the records shows some remarkable differences in the quantity of rain falling within narrow territorial limits. The following table gives a comparison of the rainfall at adjacent stations for selected showers of limited extent:

Station.	Rainfall.	Station.	Rainfall.	Distance between stations.	Date of shower.
	Inches.		*Inches.*	*Miles.*	
Monte Lirio	6.76	Brazos Brook	0.97	6	Feb. 8, 1910
Gamboa	3.21	Empire	.52	4	July 3, 1910
Gatun Evapor. Sta.	4.05	Gatun	.89	1	May 23, 1911
Gorgona	5.45	San Pablo	1.27	3.5	May 13, 1911
Miraflores	4.04	Pedro Miguel	.35	2	Dec. 30, 1912
Empire	3.36	Culebra	.59	1	June 7, 1913
Brazos Brook	3.75	Colon	.31	3	Dec. 1, 1913
Rio Grande	3.24	Pedro Miguel	.33	2.7	June 1, 1917
Empire	4.89	Gamboa	.66	4	Oct. 21, 1918

EXCESSIVE PRECIPITATION.

The greater part of the rainfall on the Isthmus comes in the form of heavy tropical downpours of short duration and relatively limited extent.

Late in the rainy season, usually in November and December, rainstorms of a more general character and of longer duration may occur. These general rainstorms frequently accompany storms of the "Norther" type and they continue at times for 24 hours or longer. Some of them extend over the entire Canal Zone and adjacent territory, while others are confined to the Atlantic coast of the Isthmus. The dry-season storms of this character are more likely to be confined to the Atlantic coast and adjacent territory. What is perhaps the heaviest general rainstorm of record on the Isthmus occurred on December 2–3, 1906, accompanying a severe "Norther." Rain began falling on the afternoon of December 2 and continued steadily, though not at a remarkably excessive rate, for nearly 24 hours.

The following table shows the amounts of precipitation recorded at the various stations during this rainstorm, which caused one of the largest freshets in the history of the Chagres River:

Station.	Rainfall.	Station.	Rainfall.
	Inches.		*Inches.*
Balboa	2.41	Gamboa	6.29
Ancon	3.18	Alhajuela	8.19
Rio Grande	5.58	Bohio	6.13
Culebra	5.55	Gatun	10.48
Camacho	5.53	Brazos Brook	8.96
Empire	6.15	Cristobal	8.47

The following table shows the maximum rainfall of record at stations in the Canal Zone and vicinity for periods of 5 minutes, 1 hour, and 24 hours:

TABLE 1.—*Maximum rainfall in Canal Zone October, 1905, to January, 1919.*

Stations.	Maximum rainfall.					
	5 minutes.		1 hour.		24 hours.[1]	
	Inch.	Date.	Inch.	Date.	Inch.	Date.
Balboa (June 10, 1906).	.90	May 12, 1912	5.86	June 2, 1906	7.57	Nov. 16–17, 1906.
Balboa Heights (Oct. 1, 1905).	.64	Aug. 7, 1908	3.98	Oct. 9, 1911	7.23	May 12–13, 1912.
Miraflores (June 19, 1914).	.50	Sept. 6, 1917	4.09	Sept. 6, 1917	4.75	Sept. 6, 1917.
Pedro Miguel (Jan. 1, 1908).	.60	Nov. 11, 1908	3.46	Sept. 6, 1917	5.45	Nov. 19–20, 1917.
Rio Grande (Dec. 29, 1905).	.75	July 24, 1908	4.14	Nov. 20, 1917	8.24	Nov. 19–20, 1917.
Empire (July 18, 1906).	.60	July 25, 1906	4.19	Oct. 21, 1908	6.15	Dec. 3, 1906.[2]
Gamboa (Nov. 18, 1905).	.59	July 27, 1908	3.32	May 11, 1911	6.56	Dec. 2–3, 1906.
Alhajuela (Mar. 31, 1907).	.60	July 20, 1909	4.19	July 8, 1915	8.19	Dec. 2–3, 1906.[2]
Gatun (Oct. 1, 1905)	.62	{Aug. 3, 1912 Aug. 12, 1914	4.72	Aug. 12, 1914	10.48	Dec. 3, 1906.[2]
Bohio (Oct. 1, 1905)	.67	June 16, 1909	4.51	Aug. 7, 1908	8.85	Aug. 7–8, 1908.
Colon (Oct. 1, 1905).	.64	Aug. 25, 1909	4.90	Oct. 8, 1909	8.53	Dec. 2–3, 1906.
Porto Bello (May 1, 1908).[3]	[4] 2.48	Nov. 29, 1911	4.53	Nov. 29, 1911	10.86	Dec. 28–29, 1909.

[1] Maximum rainfall in 24 consecutive hours.
[2] No automatic record on this date, total for 24 hours ending at noon.
[3] Station closed in August, 1914, and reopened in December, 1918.
[4] Approximate, automatic record indistinct due to unusually excessive rate of rainfall. [This rate exceeds that of 205 mm. (8.07 in.) in 20 minutes at Curtea-de-Arges, Roumania, July 7, 1889, heretofore considered the greatest on record.—ED.]
Dates in parenthesis refer to the installation of automatic raingages.

A comparison of the heaviest 24-hour rainfall recorded on the Isthmus with the heaviest known rainfalls in

other regions of excessive precipitation is presented in the following table. It will be noted that the maximum 24-hour rainfall of record on the Isthmus; approximately 11 inches, has been exceeded at several localities in the United States, where the average annual precipitation is much less than the annual average in Panama.

TABLE 2.—*Excessive rainfalls in periods of about a day.* [1]

Station.	Date.	Rainfall.		Duration.
		Inches.	Millimeters.	
Porto Bello, R. P.	Dec. 28-29, 1909	10.9	276	24 hours.
Robertsdale, Ala.	Sept. 28, 1917	17.5	444	1 day.
Catskill, N. Y.	July 26, 1819	18.0	457	7½ hours.
St. George, Ga.	Aug. 28-29, 1911	18.0	457	17 hours.
Montell, Tex.	June 28-29, 1913	20.6	523	18½ hours.
Fort Clark, Tex.	June 14-15, 1880	21.3	541	22 hours.
Alexandria, La.	June 15-16, 1886	21.4	544	24 hours.
Altapass, N. C.	July 15-16, 1916	22.22	564	Do.
Adjuntas, Porto Rico	Aug. 18, 1899	23.0	584	Do.
Hills above Bombay, India	Ency. Britannica	24.0	610	1 night.
Genoa, Italy	do	30.0	762	26 hours.
Gibraltar	do	33.0	838	Do.
Silver Hill, Jamaica	Nov. 6, 1909	30.5	775	1 day.
Nedunkem, Ceylon	Dec. 15-16, 1897	31.8	807	24 hours.
Honomu, Hawaii	Feb. 20, 1918	31.95	812	1 day.
Laupehoehoe, Hawaii	Dec. 24, 1901	41.3	1,049	28 hours.
Queensland		40.0	1,016	24 hours.
Cherrapunji, India	June 14, 1876	40.8	1,036	Do.
Baguio, Philippine Islands	June 14-15, 1911	45.99	1,168	Do.

[1] Table amplified by Editor, mostly from MONTHLY WEATHER REVIEW, and Engineering News Record, vol. 76, p. 1001, 1916.

It is possible that quantities of rain greater than any listed above have fallen over very limited areas in the southern and southwestern sections of the United States.

The record of 45.99 inches of rainfall in 24 hours at Baguio, P. I., on July 14–15, 1911, during the passage of a severe typhoon is, so far as known, a world's rainfall record for a period of 24 consecutive hours.

Table No. 4 gives a comparison of the annual precipitation at Canal Zone stations and selected stations in the United States, while table No. 5 presents the monthly precipitation for maximum, minimum and average years at the principal stations in the Canal Zone and vicinity.

TABLE 3.—*Excessive rainfalls in periods of 5 minutes to 4 hours.* [1]

Station.	Date.	Rainfall.		Duration.
		Inches.	Millimeters.	
Porto Bello, R. P.	May 1, 1908	[2] 2.48	63	5 minutes.
Balboa, C. Z.	June 10, 1906	0.9	23	Do.
Fort McPherson, Nebr.	May 27, 1868	1.5	38	Do.
Paterson, N. J.	July 13, 1880	1.5	38	8 minutes.
Galveston, Tex.	June 4, 1871	3.9	100	14 minutes.
Curtea-de-Arges, Roumania	July 7, 1889	8.1	205	20 minutes.
Guinea, Va.[3]	Aug. 24, 1906	[2] >9.25	>235	About 30 minutes.
		[2] >11.5	>292	Est. 30–45 minutes.
Newtown, Pa.	Aug. 5, 1843	5.5	140	40 minutes.
Tridelphia, W. Va.	July 19, 1888	6.9	175	55 minutes.
Palmetto, Nev	Aug. 7, 1890	8.8	224	1 hour.
Campo, Calif.	Aug. 12, 1891	[2] 11.5	292	80 minutes.
Newtown, Pa.	do	13	330	3 hours.
Concord, Pa.	do	[2] 16	406	Do.
Basseterre, St. Kitts	Jan. 12, 1880	[2] 23±	abt. 584	4 hours.

[1] Table amplified by Editor, largely from Greely's "American Weather," New York, 1888; and MONTHLY WEATHER REVIEW. See also table by C. P. Birkinbine, p. 59, in A. P. Towell's, "Sewerage," New York, 1918.
[2] Probably world's records.
[3] Pails ran over. See MONTHLY WEATHER REVIEW, 1906, 34, pp. 406–407.

TABLE 4.—*Annual precipitation.*

Station.	Maximum year.		Minimum year.		Annual mean (inches).	Years of record.
	Inches.	Year.	Inches.	Year.		
Colon	183.41	1909	86.54	1884	129.04	48
Gamboa	136.19	1887	70.67	1911	91.61	36
Balboa	93.06	1909	50.90	1918	68.44	20
New York	59.68	1859	28.78	1835	42.47	84
Indianapolis	57.65	1876	30.33	1901	40.99	45
St. Louis	68.83	1858	23.28	1871	40.10	73
Kansas City	50.25	1898	19.04	1896	37.69	41
Denver	22.96	1909	7.75	1911	14.52	44
Salt Lake City	23.64	1875	10.33	1890	16.33	35
San Francisco	38.82	1884	9.31	1898	23.25	62
Los Angeles	40.29	1884	4.83	1898	15.58	34
Indio, Calif.	7.10	1906	Trace.	1894	2.76	34
Phoenix	19.73	1905	3.77	1885	7.39	35
El Paso	21.81	1856	2.22	1891	9.06	42
New Orleans	85.73	1875	31.07	1899	56.63	63
Key West	69.69	1870	22.00	1893	38.40	58

TABLE 5.—*Monthly rainfall for maximum and minimum years, and averages.*

[Inches.]

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Porto Bello:													
Maximum year 1909	20.90	6.83	3.56	12.56	9.69	17.70	26.33	13.83	13.99	8.70	45.03	58.17	237.28
Minimum year 1912	.67	1.64	.60	.54	16.65	19.77	24.21	14.15	15.03	17.01	25.82	11.52	147.61
6-year average	7.51	4.13	2.49	5.86	17.74	16.12	19.77	18.93	13.28	12.53	30.16	20.63	169.15
Bocas del Toro:													
Maximum year 1910	33.66	6.98	3.61	17.30	13.97	10.13	17.20	7.61	5.27	3.16	6.54	21.45	146.87
Minimum year 1915	2.37	9.90	8.21	10.09	7.07	4.55	7.59	8.20	2.55	4.64	6.35	5.92	77.44
10-year average	10.18	8.64	5.83	8.67	11.40	7.47	14.09	10.48	6.06	5.81	11.06	12.98	112.67
Colon:													
Maximum year 1909	10.61	1.92	1.85	3.56	7.21	17.49	12.83	15.42	16.33	19.31	42.50	34.38	183.41
Minimum year 1884	3.39	.39	.39	4.33	10.16	10.32	15.59	13.27	9.37	8.66	7.05	3.62	86.54
48-year average	3.85	1.67	1.61	4.21	12.71	13.38	16.02	15.00	12.67	14.89	21.34	11.69	129.04
Alhajuela:													
Maximum year 1909	2.72	3.71	.29	3.54	14.32	19.73	13.64	8.15	7.50	19.32	36.22	22.90	152.04
Minimum year 1913	.96	.22	.08	.72	12.63	11.51	6.99	10.92	8.82	6.41	16.56	1.59	77.41
19-year average	1.03	.78	.49	3.68	12.25	12.51	12.44	12.51	11.69	14.01	14.35	5.94	101.68
Gamboa:													
Maximum year 1887	2.20	.08	.28	6.85	11.03	19.45	14.02	19.17	11.50	14.88	24.06	12.68	136.20
Minimum year 1911	.11	.71	.38	4.01	14.53	6.98	7.26	7.68	5.20	12.75	10.09	.97	70.67
36-year average	1.77	.86	.74	3.60	10.83	9.73	10.21	11.90	10.41	12.79	12.01	6.62	91.61
Culebra:													
Maximum year 1896	2.34	.39	3.06	16.70	7.40	7.08	8.18	17.70	8.35	8.10	24.10	3.64	107.04
Minimum year 1888	.24	.02	.53	.33	11.41	7.99	2.92	6.55	11.28	5.75	9.55	7.71	64.28
28-year average	1.60	.67	.58	3.69	11.14	8.84	9.43	10.05	10.74	11.43	12.42	6.90	87.49
Balboa:													
Maximum year 1909	1.45	1.69	.14	2.83	9.69	13.06	14.92	6.86	4.11	11.20	15.99	12.12	93.06
Minimum year 1918	1.02	.00	1.32	4.33	6.45	4.57	4.32	3.75	6.58	8.52	8.62	1.42	50.90
20-year average	1.07	.63	.67	3.80	8.18	7.30	8.06	7.62	6.97	9.32	9.31	5.51	68.44
Naos Island:													
Maximum year 1906	.31	.29	.02	6.56	7.21	11.34	8.79	5.89	3.29	3.76	16.76	4.74	68.96
Minimum year 1882	.00	.02	.02	.94	4.58	5.09	1.64	1.14	1.12	2.72	5.03	2.84	25.14
10-year average	.43	.11	.31	2.05	5.43	6.59	4.76	5.10	6.70	6.12	7.17	3.16	47.93

[To face p. 302.]

FIG. 1.—"Sacred" lake, near summit of Mount Waileale, said to have been used by ancient Hawaiians for ceremonial purposes. (Photo by W. F. Martin.)

FIG. 2.—U. S. Geological Survey topographers mapping Mount Waileale summit. (Photo by W. F. Martin.)

FIG. 3.—A U. S. Geological Survey high-level 48-inch rain gauge protected against wild cattle. (Photo by W. F. Martin.)

[To face p. 303.]

FIG. 4.—Typical upper valley spring on windward Oahu. (Photo by W. F. Martin.)

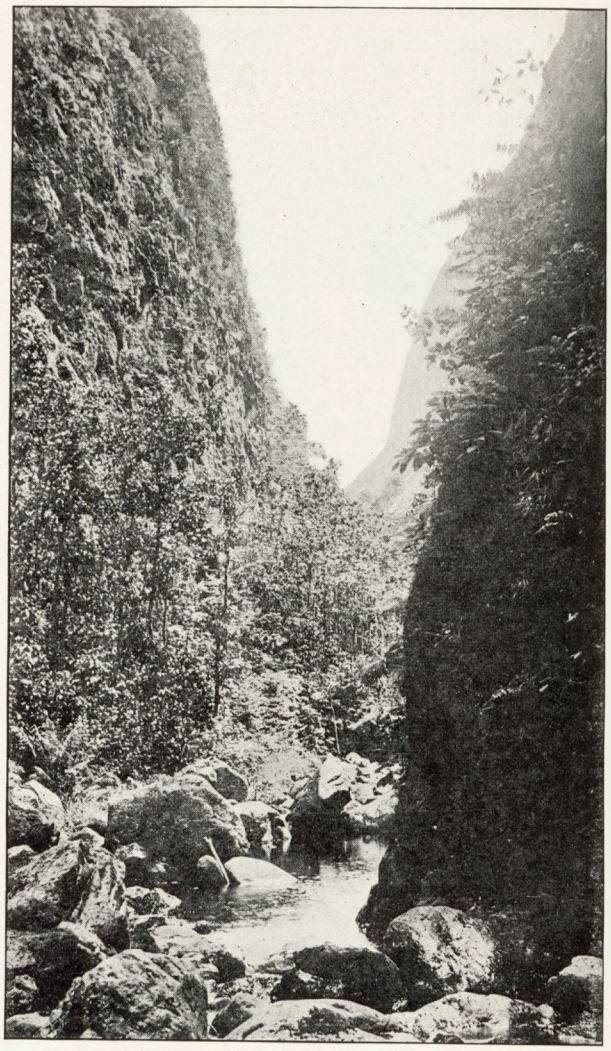

FIG. 5.—Typical mountain valley. (Note sharp topography.) (Photo by W. F.Martin.)

FIG. 6.—Typical Hawaiian mountain stream. (Photo by W. F. Martin.)